Contract #: DE-SC0011963 Program Manager: Dr. Imre Gyuk Technical Point of Contact: Dr. Stan Atcitty

Highly Efficient, High Power Density GaN-based DC-DC Converters for Grid-Tied Energy Storage Applications

APEI

Department of Energy Phase I SBIR

Daniel Martin, PhD

Senior Staff Engineer, Switched-Mode Power Supplies

September 18, 2014

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Acknowledgments

I would like to thank **Dr. Imre Gyuk** of the DOE Energy Storage Program for funding this work and **Dr. Stan Atcitty** for his technical contributions.

APEI

SBIR Program Goals and Timeline

Design and develop a high efficiency (>98%) power dense (>10 kw/L) bidirectional GaN based DC-DC converter for energy storage applications

Phase I — Phase II — Phase III

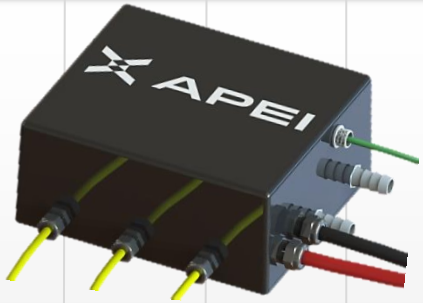
2014 — 2015 — 2016 — 2017 — 2018 — 2019

Develop a general hardware platform capable of using GaN, SiC, and SI

Evaluate the benefits of GaN and begin Ph. II design

Start Program

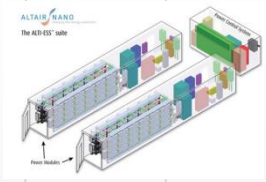
Key Deliverables: GaN DC-DC converter demonstrator and design



Design, build and test a >50 kW DC-DC for use in ESS

Key Deliverables: >50 kW DC-DC Converter

Interface converter between battery storage and Grid-tied inverter



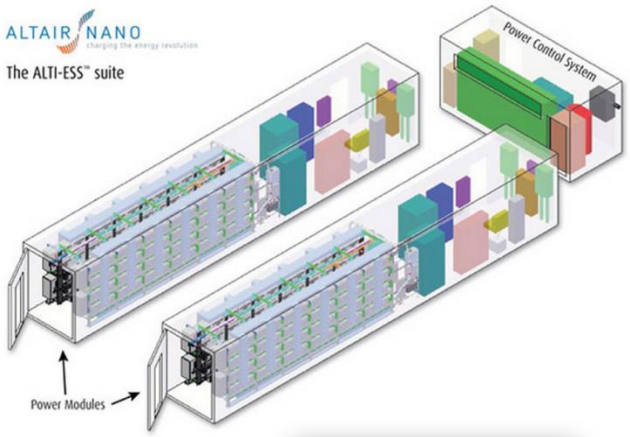
Fully qualify DC-DC converter for use in commercial applications

APEI, Inc. will work with its partners to transition this DC-DC converter technology to a commercial product

APEI

Program Target Applications

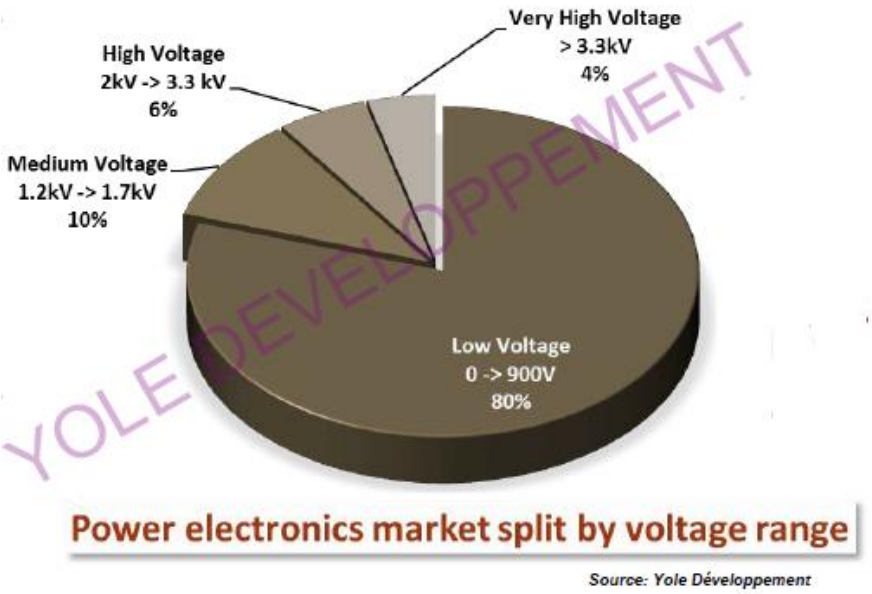
- Residential and light commercial (<10 kw)
  - Renewable energy storage and interface converter
  - Hybrid Electric/Electric vehicle
- Industrial (10 kW to MW scale)
  - Renewable energy storage and interface converter
  - Uninterruptible power supplies
  - Hybrid Electric/Electric heavy vehicle (locomotives, heavy machinery)



Power Electronics and Energy Storage Markets

Power Electronics Market

- **< 900 V** – GaN set to grow greatly in this area. GaN has the potential to offer higher performance and lower cost.
- **> 1.2 kV** – Currently, ideal Area for SiC; GaN research being done to penetrate this market



Power electronics market split by voltage range

Source: Yole Développement

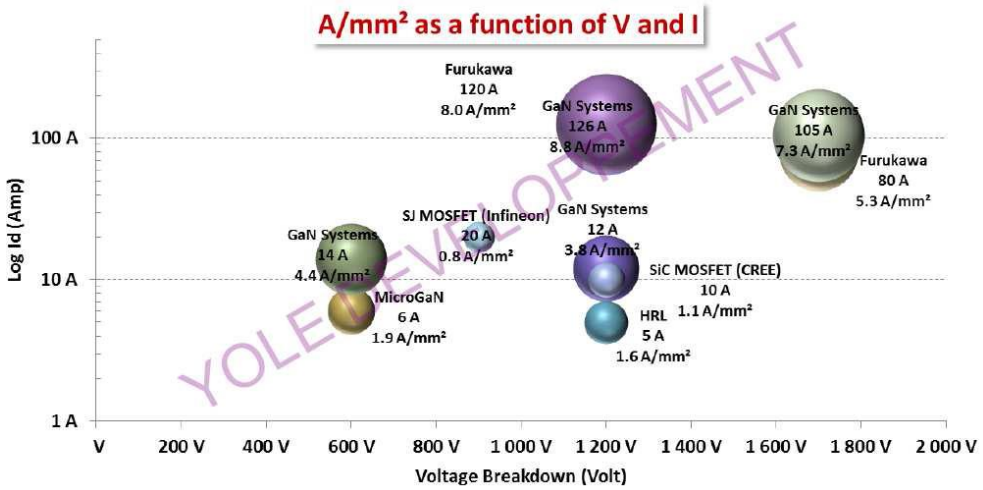
Energy Storage Market

- The global energy storage market is expected to grow from $39.7B in 2011 to $61.9B by 2016 at an annual growth rate of 9.3% [1]

[1]. http://www.marketresearch.com/MarketsandMarkets-v3719/Advanced-Energy-Storage-Technologies-Type-6671586/

APEI

Advantages of GaN



- Extremely fast switching which enables:
  - Smaller/less expensive filtering elements
  - Lower switching loss increases efficiency and reduces cooling requirements
- Cascode arrangement enables:
  - Simple drive requirements (Si MOSFET front end)
  - Usable anti-parallel diode
- GaN on Si enables lower cost than SiC

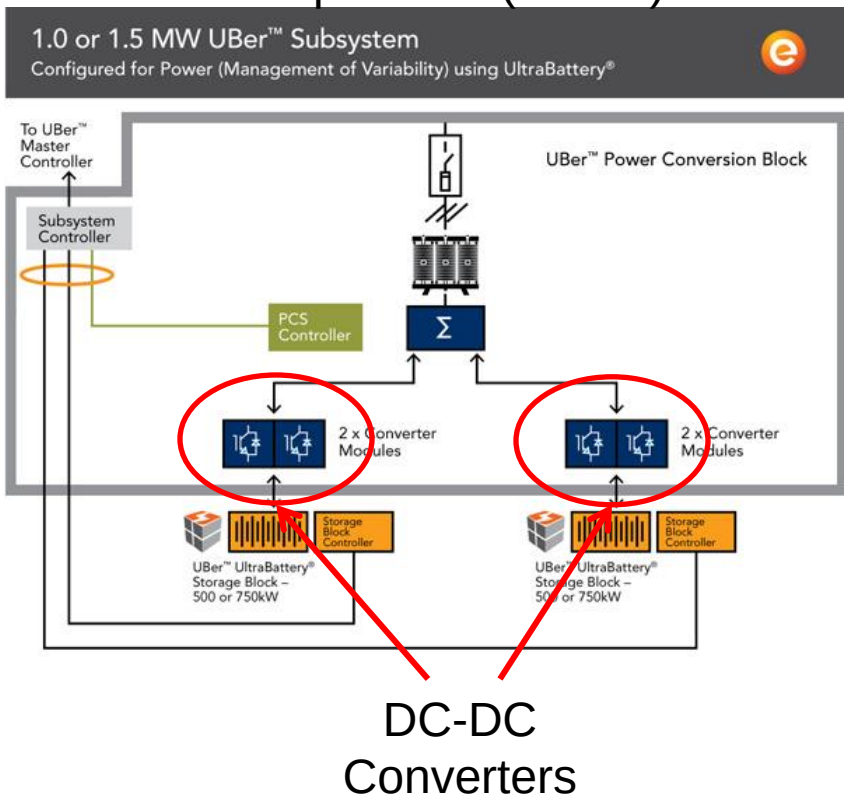
"Power GaN: Market & Technology Analysis," Yole Developpment.

APEI

Need for High Efficiency DC-DC Converters in Energy Storage Systems

- High efficiency DC-DC converters provide critical functionality in energy storage systems
  - They provide galvanic isolation (safety)
  - They are inherently capable of providing circuit breaker functionality
  - They interface the inverter to the batteries
  - They control the charging/discharging of batteries
- **High efficiency is critical and can significantly decrease wasted energy, operational cost, and payback period**

Example ESS (Ecoult)



DC-DC Converters

Need for Bidirectional Power Flow

Power Flow to Grid

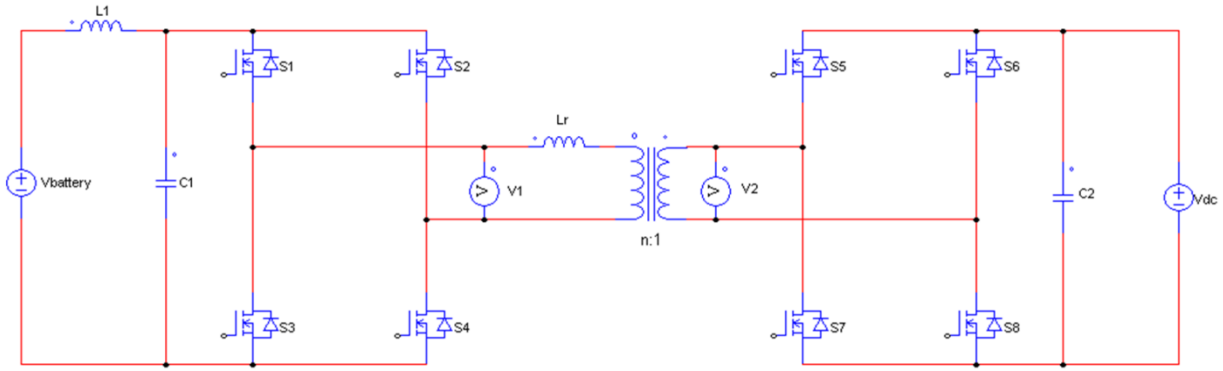
Battery System → **DC-DC Converter** → DC-AC Converter (Inverter)

Power Flow to Battery

Battery System → **DC-DC Converter** → DC-AC Converter (Rectifier)

APEI

Technical Approach

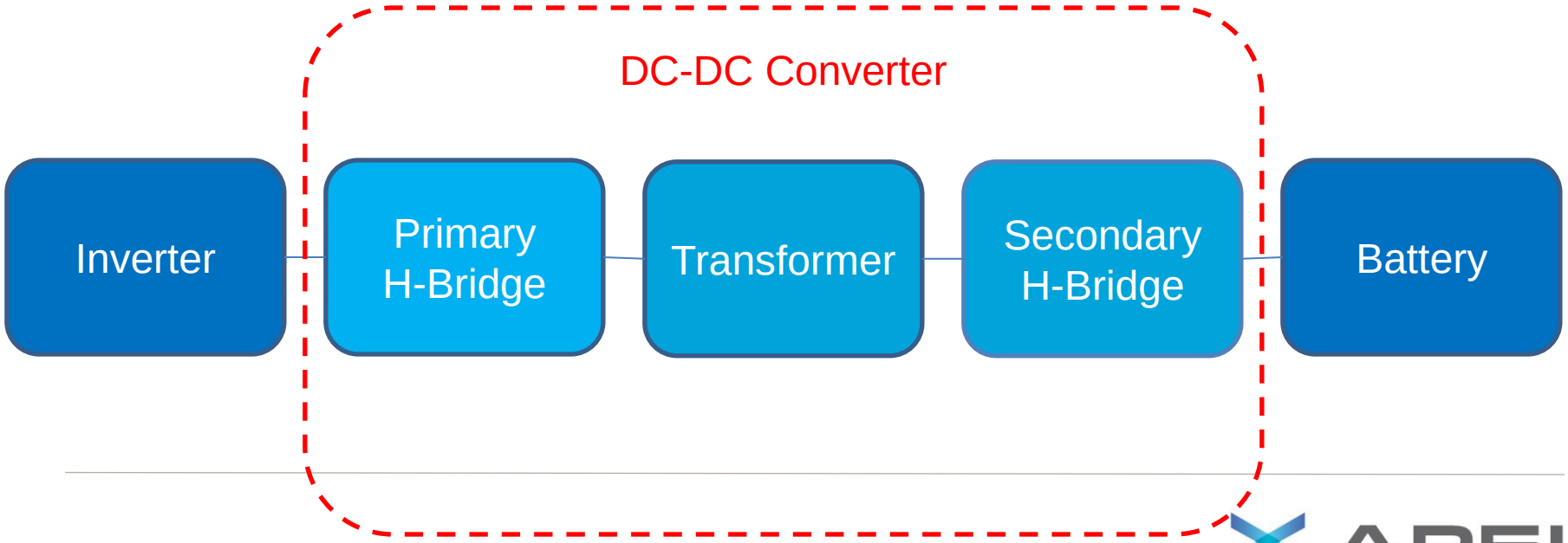


- Dual Active Bridge (DAB) topology
  - Power bidirectional
  - Soft switching topology decreases switching loss
  - High frequency isolation transformer enables galvanic isolation in a small volume
  - Scalable from 100's of watts to MWs
- Modular approach
  - GaN, SiC, and Si full bridges will be constructed to evaluate the each devices performance

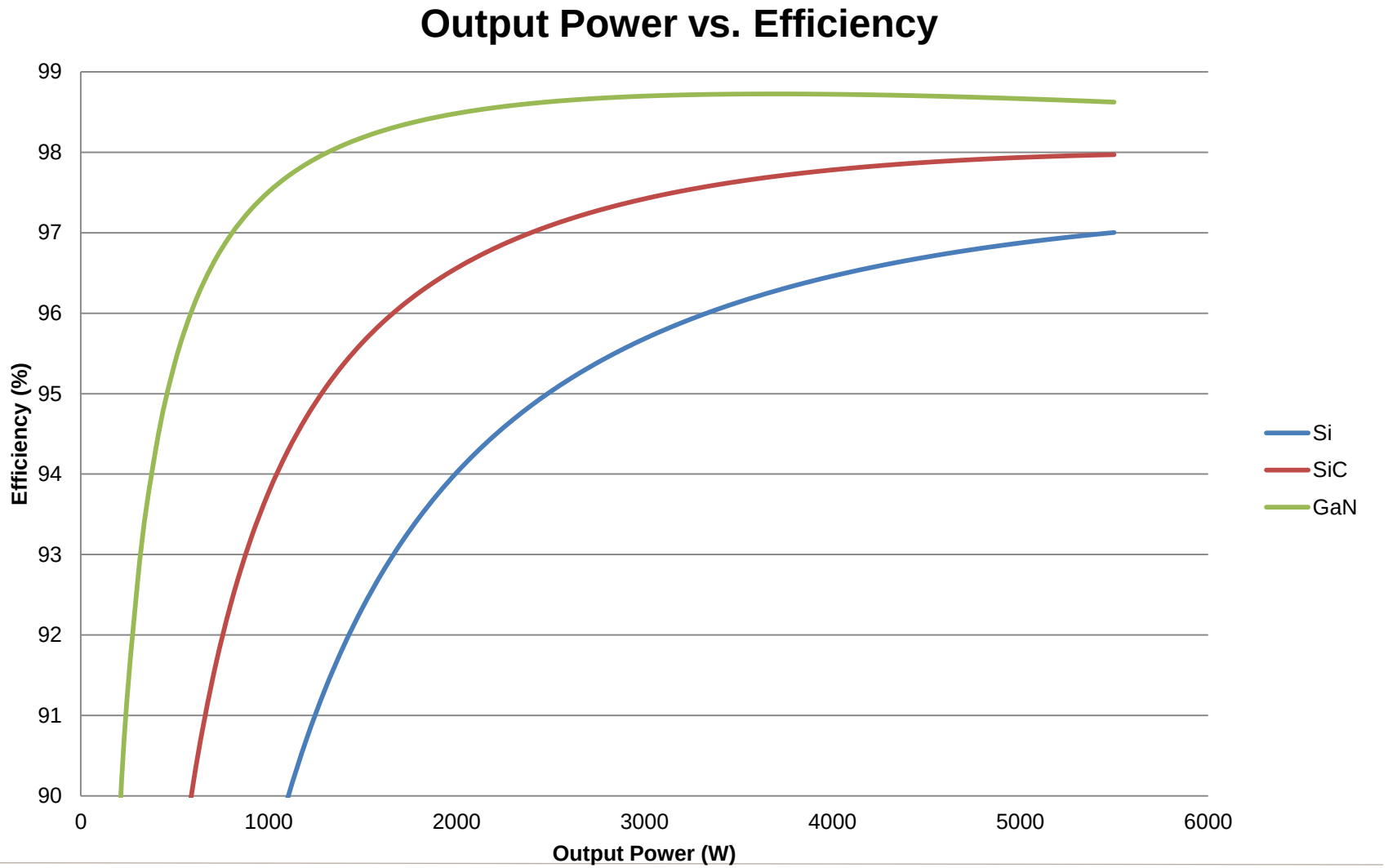
APEI

Device Comparison

- Since they DAB introduces a logical split between primary and secondary different devices can be compared easily:
  - GaN/GaN, SiC/SiC, Si/Si, GaN/SiC, GaN/Si, SiC/Si
- Multiple configurations will be tested for efficiency to determine how each device can benefit the system

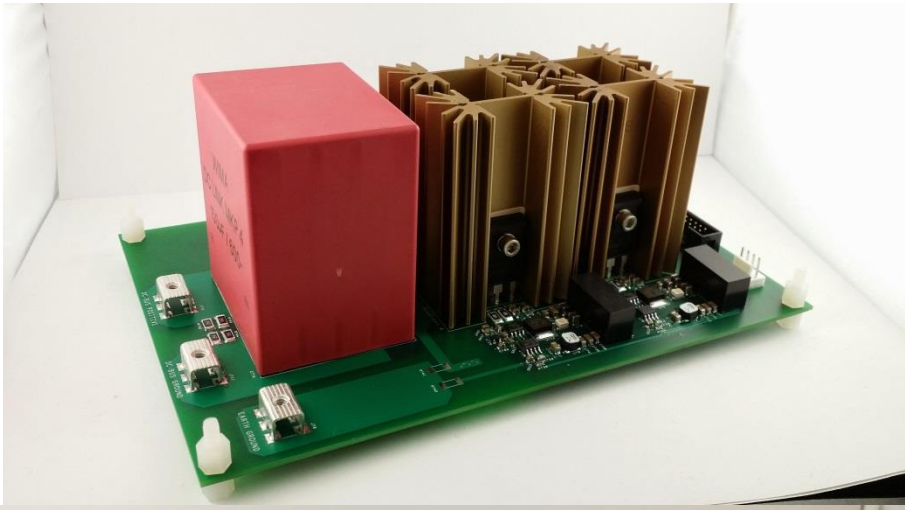


Initial Simulation Results

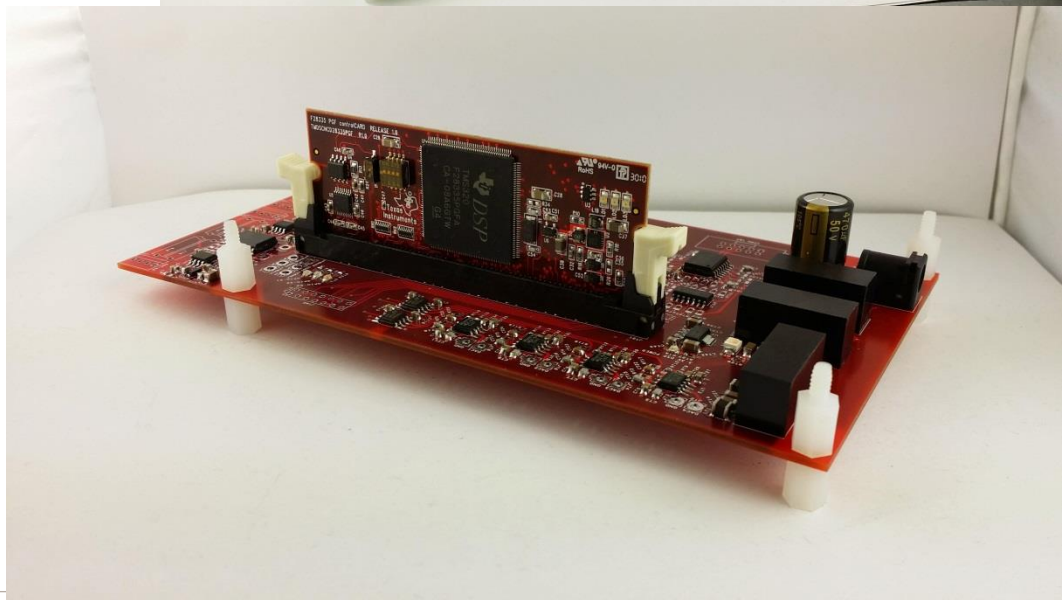


Hardware Prototype

- The full bridge (pictured right) is used as one half of the dual active bridge. Each full bridge uses either 4 : 40 mΩ SiC MOSFETs, 40 mΩ Si MOSFETs, or 45 mΩ GaNFETs



- The control board pictured right will sense voltages and currents and provide feedback control by controlling the gating signals of the full bridge boards



APEI

Phase I Tasks

- Converter Design
  - Finalize specifications (complete)
  - Parts selection (complete)
  - Design and build (in progress)
  - Testing and optimization
- GaN Power Module Design
  - Device and material selection
  - Layout design
  - Thermal/Mechanical/Electrical simulation

APEI

Summary

- High efficiency bidirectional DC-DC converters are critical for current and future energy storage systems
- GaN transistor technology can greatly improve efficiency compared to Si technology
- The DC-DC converter demonstrator deliverable for Phase I is nearly complete and awaiting testing
- Once complete, a higher power (>50 kw) design for Phase II will begin utilizing a custom GaN power module

APEI

Questions?

APEI